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CORRELATIONS BETWEEN MORPHOLOGICAL CHARACTERS AND THE SACCHARINE CONTENT OF SUGAR BEETS

Frederick J. Pritchard

In nearly every line of plant or animal improvement, the breeder strives to attain an ideal type which, from study and experience, is known to be correlated with desirable qualities. As long as selection towards an ideal type is confined to characters which bear the desired qualities as constituent elements, as, for instance, size, length and tensile strength of cotton or woolen fiber, this practice appears to be sound. Often, however, in forming the ideal type, a distinction is also made between characters which do not bear the qualities sought, but which are supposed to have a fundamental connection with their development. Before making distinctions between characters of the latter class it would seem desirable to ascertain (1) what the relative merits of the mutually exclusive characters of the organism are with respect to its quality and productiveness and (2) whether highest quality and maximum production are really dependent upon a particular combination of such characters. The present investigation is directed along these lines, but is limited to a study of the sugar beet.

Material

All the material, except that used in computing the biometrical constants for table II, consisted of five American varieties of sugar beets grown by the Office of Sugar Plant Investigations, at Brookings, South Dakota, in 1910, in co-operation with the South Dakota Experiment Station. About an equal number of beets were taken at random from each variety to compile the data.

The chemical analyses were made by Guy Youngberg, under the direction of James H. Shepard, station chemist.

Investigation

The correlations which obtain between mutually exclusive characters of the sugar beet plant and its percentage or quantity of sugar seem to depend upon the structural relationship of its different parts. The tissues of the root as shown in cross-section (fig. 1) show a concentric appearance resembling the annual rings of a tree. Wood-zones alternate with zones of parenchyma.[1] The former[2] are richer in sugar than the latter, hence the greater the number of wood-zones and the closer they lie together, the richer the root.

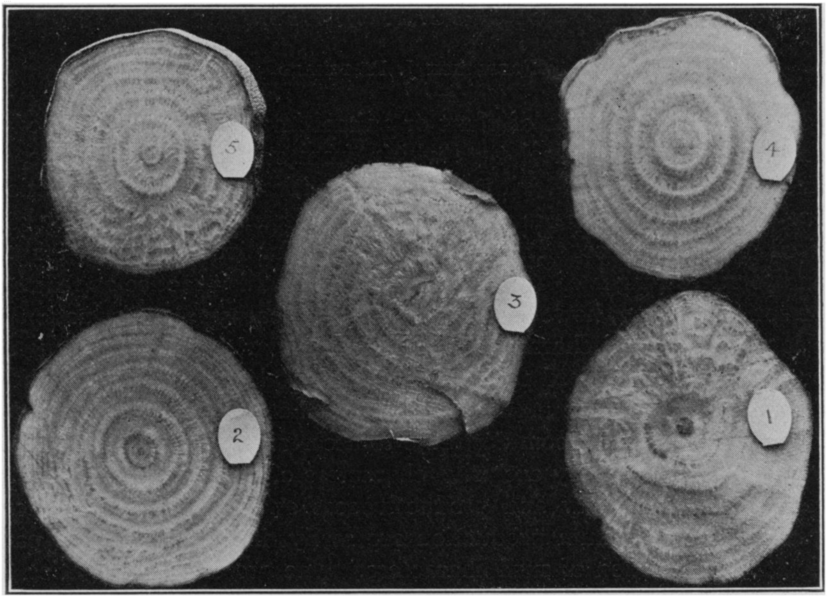

FIG. 1. Cross-sections of sugar beet roots showing wood-zones and parenchyma-zones. (Photograph by Harry B. Shaw.) Sections 2, 4, and 5 are cut from the root; sections 1 and 3 from the lower part of the crown.

The percentage of sugar in the beet depends somewhat upon the size of the root. As small roots usually have as many zones of wood as large roots and relatively less parenchyma, they contain the higher average percentage of sugar. The relationship between percentage of

[1] Bundles from adjacent wood-zones frequently anastomose, but the zones are fairly distinct in cross-section, except in the crown, where they run obliquely.

[2] Samples of 30 roots separated into wood-zones and parenchyma-zones and analyzed separately showed an average difference of 2.6 percent sugar in favor of the wood-zones. This is due to the greater abundance of sugar in the sieve cells and prosenchyma immediately surrounding the bundles.

sugar and size of root as found in beets at Brookings in 1910 is shown in table I.

TABLES I, III-*b* AND IV

Summary of Biometrical Constants

Number of Table	Number of Roots Analyzed	Characters Employed	Mean	Standard Deviation	Coefficient of Variability	Coefficient of Correlation
I	3,784	Percentage of sugar in beet..	17.67± .017	1.59± .012	8.99±.069	
		Weight of individual roots, in grams........	458.52±1.64	149.70±1.16	32.64±.278	−.258±.010
III-*b*	3,784	Percentage of sugar in beet..	17.67± .017	1.59± .012	8.99±.069	
		Quantity of sugar per root in grams........	79.87± .266	23.94± .186	29.97±.263	.005±.011
IV	3,784	Quantity of sugar as per root in grams........	79.87± .266	23.94± .186	29.97±.263	
		Weight of root in grams........	458.52±1.64	149.70±1.16	32.64±.278	.92 ±.0016

The table shows that small roots are richer on the average than larger roots, that the correlation is negative and amounts in this case to —.258. Since correlation varies between 1.00 and —1.00, —.258 represents a fairly large coefficient.

For the purpose of further comparison, similar calculations were made from four groups of beets grown at Fairfield, Washington, and the results summarized in table II.

TABLE II

Correlation between Percentage of Sugar and Weight of Root of Beets Grown at Fairfield, Washington

Group	Year	No. of Roots	Coefficient of Correlation	Percentage of Sugar		Weight of Roots, Ounces	
				Mean	Standard Deviation	Mean	Standard Deviation
a	1907	230	−.284±.041	21.15±.056	1.26±.039	22.39±.311	6.99±.219
b	1909	400	−.499±.025	20.37±.049	1.47±.035	20.70±.025	7.61±.181
c	1910	400	−.257±.031	17.34±.044	1.31±.031	19.00±.290	8.61±.205
d	1910	400	−.253±.032	18.76±.042	1.25±.029	20.71±.213	6.32±.151

These coefficients of correlation are practically the same as those of the preceding table, except for the year 1909. All show a relatively high negative correlation, confirming the general statements of Briem, v. Proskowitz (cited by Fruwirth (1)), and v. Rümker (2), and the statistical results of Harris and Gortner (3)[3]. The regression equations for each of the foregoing tables have been calculated by means of the formula

$$p = \left(p - r\frac{\sigma p}{\sigma w}w\right) + r\frac{\sigma p}{\sigma w}w,^{3}$$

and the relationships expressed in the following graphs (figs. 2 to 6) which also include the empirical means.

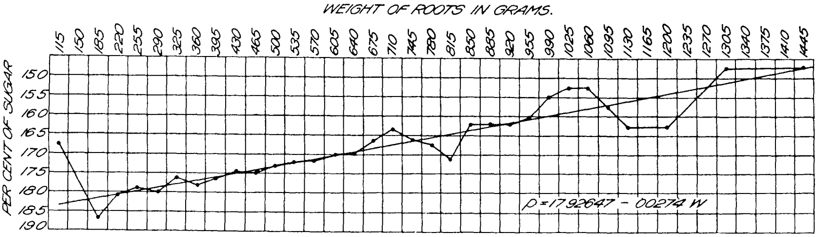

Fig. 2. Relationship between percentage of sugar in the beet and weight of root. (To accompany table I.)

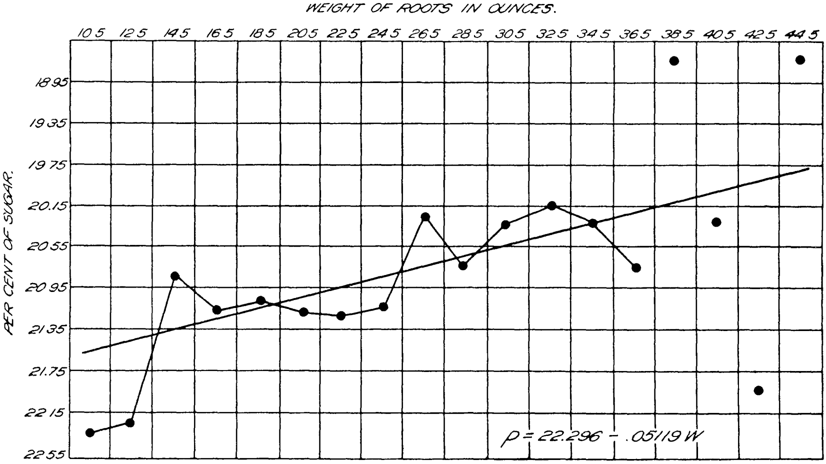

Fig. 3. Relationship between percentage of sugar in the beet and weight of root. (To accompany table II, group *a*.)

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[3] p equals percentage, w equals weight, r equals coefficient of correlation, the sigmas indicate the standard deviations of the two variables and the bars indicate means.

There is a decrease in figure 2 of 35 × .00274 or .0959 percent sugar for each increase of 35 grams in weight. As the weight of roots in the remaining figures (3–6) is expressed in ounces, the regression in percentage of sugar for each unit of weight is somewhat larger than in figure 2 as may be seen in the second member of their respective equations.

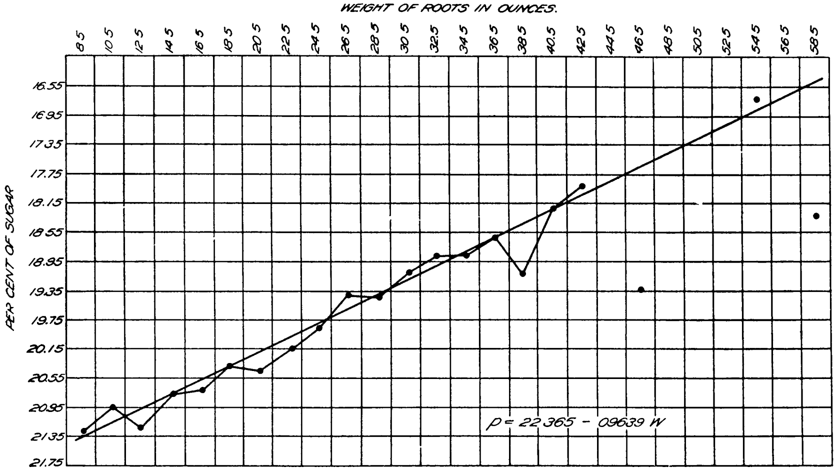

FIG. 4. Relationship between percentage of sugar in the beet and weight of root. (To accompany table II, group *b*.)

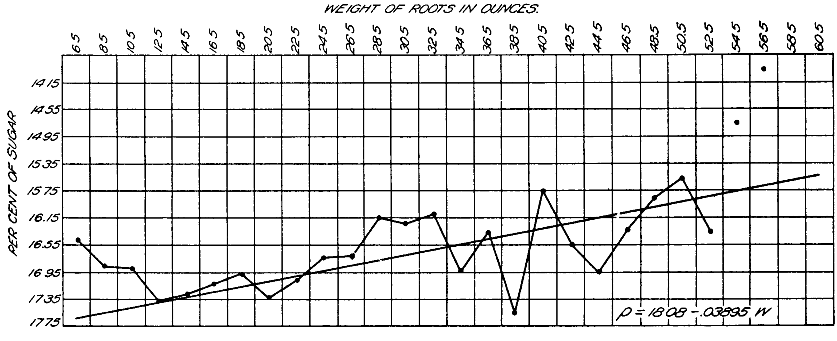

FIG. 5. Relationship between percentage of sugar in the beet and weight of root. (To accompany table II, group *c*.)

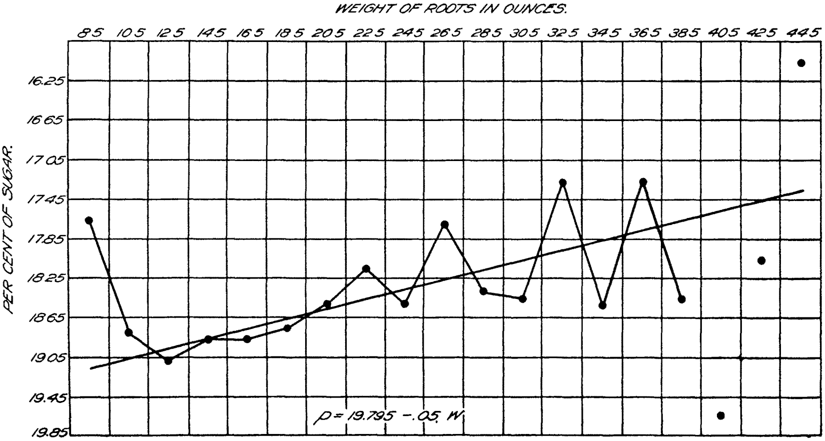

FIG. 6. Relationship between percentage of sugar in the beet and weight of root. (To accompany table II, group *d*.)

The correlation between percentage and quantity[4] of sugar found in beet roots of approximately equal weight is shown in table III *a*.

TABLE III-*a*

Correlation Between Percentage and Quantity of Sugar per Root, in Roots of Approximately Equal Weight

No. of Roots	Weight of Roots in Grams	Percentage of Sugar		Quantity of Sugar		Coefficient of Correlation
		Mean	Standard Deviation	Mean	Standard Deviation	
417	413–447	17.75±.049	1.49±.035	73.86±.221	6.69±.156	.99±.001
371	448–482	17.70±.050	1.44±.035	82.35±.252	7.21±.178	.93±.004
313	483–517	17.40±.057	1.51±.041	87.22±.289	7.59±.205	.96±.003

Although the weight of each group of roots covers a range of 35 grams, the correlation between percentage and quantity of sugar per root is nearly perfect, varying in the calculations from .93 to .99.

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[4] As the roots belonged to our breeding material and were to be used for growing seed they were not topped before weighing. The quantity of sugar was calculated on the total weight of root and crown, *i. e.*, the total weight of root was multiplied by the percentage of sugar. As the crown and tail-end of the root contain a relatively low percentage of sugar the calculated quantities of sugar are somewhat higher than those actually present.

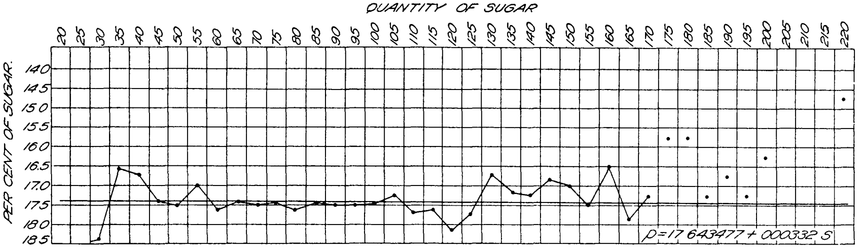

FIG. 7. Relationship between percentage and quantity of sugar per root (To accompany table III-*b*.)

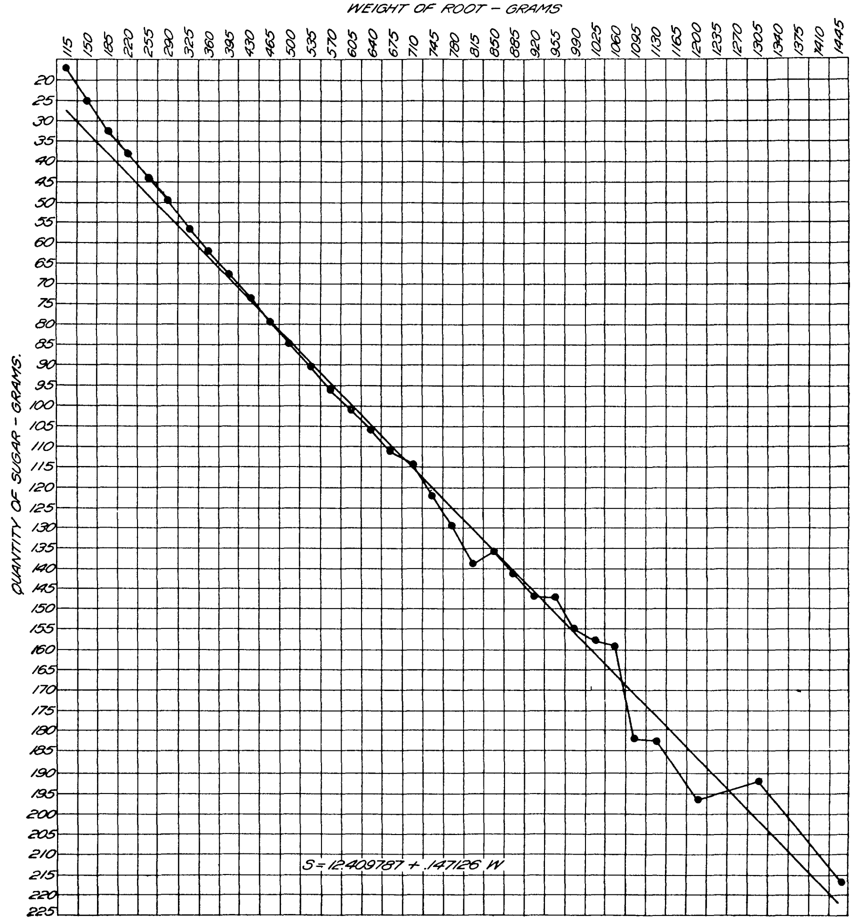

FIG. 8. Relationship between quantity of sugar and weight of root.

TABLES V–XV.

Number of Table	Relationship Between Saccharine Content of Root and	Number of Plants	Weight of Root in Grams. Mean	Quantity of Sugar per Root in Grams		Percentage of Sugar in the Beet	
				Mean	Standard Deviation	Mean	Standard Deviation
V	Shape of root						
	pyriform	1,920	443	78.28± .35	23.16± .25	17.67±.02	1.58±.02
	conical	1,348	452	80.18± .44	24.00± .31	17.75±.03	1.59±.02
	napiform	355	458	80.70± .85	23.93± .60	17.63±.06	1.54±.04
	fusiform	77	510	88.24±2.07	26.96±1.46	17.30±.12	1.56±.08
	cylindrical	84	590	99.88±1.92	26.19±1.36	16.93±.14	1.91±.10
VI	Shape of crown						
	flat..........	961	494	87.17± .55	25.73± .39	17.63±.04	1.63±.03
	rounded	2,579	438	77.63± .30	22.83± .21	17.74±.02	1.56±.01
	conical	244	433	74.83± .94	21.92± .66	17.30±.06	1.74±.05
VII	Character of root furrows						
	direction						
	intermediate	1,462	448	79.36± .40	22.76± .28	17.70±.03	1.56±.02
	vertical	1,874	454	80.15± .38	24.76± .27	17.67±.02	1.61±.02
	spiral	448	455	80.54± .76	24.09± .54	17.70±.05	1.55±.03
	depth						
	medium	1,321	442	78.36± .43	23.24± .30	17.71±.03	1.57±.02
	shallow	1,141	445.	78.10± .48	24.45± .34	17.55±.03	1.64±.02
	deep	1,322	468	82.91± .44	23.87± .31	17.72±.03	1.53±.02
VIII	Growing habit of foliage						
	erect	614	468	81.33± .67	24.94± .49	17.37±.04	1.61±.03
	semi-erect	2,852	445	78.98± .29	23.65± .21	17.74±.02	1.59±.01
	flat	318	482	85.03± .89	23.72± .63	17.65±.04	1.00±.03
IX	Color of foliage						
	light green	60	455	79.33±2.28	26.21±1.61	17.44±.15	1.75±.10
	medium	53	440	77.17±1.64	17.81±1.16	17.54±.14	1.53±.10
	dark	3,671	452	79.92± .26	23.97± .18	17.68±.02	1.58±.01
X	Leaf dimension						
	length						
	short	496	411	72.78± .62	20.77± .44	17.69±.05	1.57±.03
	medium	2,695	450	79.60± .30	23.51± .21	17.70±.02	1.55±.01
	long	593	497	87.05± .72	26.24± .51	17.50±.05	1.70±.03
	breadth						
	narrow	105	455	80.52±1.41	21.48± .99	17.70±.12	1.77±.08
	medium	3,599	449	79.30± .26	23.63± .18	17.68±.02	1.57±.01
	wide	80	605	104.75±2.28	30.33±1.61	17.31±.13	1.70±.09
XI	Character of leaf surface						
	smooth	3,500	448	79.70± .27	23.85± .19	17.79±.02	1.58±.01
	wrinkled	284	477	82.04± .99	24.83± .70	17.21±.07	1.72±.05

TABLES V–XV.—*Continued*

Number of Table	Relationship Between Saccharine Content of Root and	Number of Plants	Weight of Root in Grams. Mean	Quantity of Sugar per Root in Grams		Percentage of Sugar in the Beet	
				Mean	Standard Deviation	Mean	Standard Deviation
XII	Leaf texture						
	fine	344	461	80.84 ± .84	23.34 ± .60	17.53 ± .06	1.74 ± .04
	medium	2,521	453	79.99 ± .32	24.17 ± .22	17.65 ± .02	1.59 ± .02
	coarse	919	445	79.18 ± .52	23.49 ± .36	17.79 ± .03	1.48 ± .03
XIII	Character of leaf margin						
	undulate	882	449	79.68 ± .53	23.67 ± .38	17.73 ± .03	1.57 ± .03
	sinuate	803	430	75.72 ± .54	23.03 ± .38	17.60 ± .04	1.59 ± .03
	curly	2,099	461	81.54 ± .35	24.19 ± .25	17.69 ± .02	1.58 ± .02
XIV	Petiole dimension						
	length						
	short	357	439	77.55 ± .76	21.43 ± .54	17.67 ± .05	1.46 ± .04
	medium	1,297	445	79.13 ± .43	23.13 ± .30	17.80 ± .03	1.56 ± .02
	long	339	459	80.40 ± .85	23.44 ± .60	17.50 ± .06	1.70 ± .04
	breadth						
	narrow	998	420	74.02 ± .46	21.60 ± .32	17.61 ± .03	1.60 ± .02
	medium	2,349	452	80.20 ± .32	23.18 ± .22	17.75 ± .02	1.58 ± .02
	wide	437	525	91.50 ± .90	28.17 ± .64	17.43 ± .05	1.70 ± .04
XV	Depth of petiole groove						
	shallow	1,159	419	74.12 ± .46	23.36 ± .32	17.67 ± .03	1.61 ± .02
	medium	1,282	444	78.51 ± .43	23.04 ± .30	17.70 ± .03	1.57 ± .02
	deep	1,343	479	84.61 ± .45	24.46 ± .31	17.66 ± .03	.571 ± .02

When root weight is variable however a very different relationship obtains between percentage and quantity of sugar as shown in table III *b* and its accompanying graph (fig. 7).

There is apparently no correlation between percentage and quantity of sugar in beet roots of miscellaneous weights.

The correlation found between the size of the root and the quantity of sugar it contains is shown in table IV.

The coefficient of .92 is very high. Calculating the regression equation and expressing this relationship in the form of a graph (fig. 8) we obtain a striking illustration of the role of size in influencing the quantity of sugar independently from the percentage of sugar.

The shape of a beet root as shown by Plot (4) and others, affects its sugar content. The five most common forms were studied and their relative values recorded in table V. The relative frequency of each type corresponds to its numerical proportion of the number of plants in each group.

As shown by the table, the cylindrical roots were lowest in percentage but highest in quantity of sugar. The conical form had the highest average percentage, but when the probable errors are considered there is no real difference between it and the pyriform and napiform types.

The relative merits of three different types of crown, viz., flat, rounded and conical, were also determined and the results summarized in table VI.

Beets having flat crowns were heaviest and contained a slightly higher percentage of sugar than roots possessing conical crowns, which is contrary to expectation, as the larger roots, as a rule, contain the lower percentage—a difference of 35 grams in weight being equivalent to a difference of about 1-10 of one percent sugar (cf. fig. I). The conical crown, therefore, appears to be a detrimental character as it is correlated with both a low percentage and a small quantity of sugar.

Deep, spiral root-furrows are said to denote contraction or density of the root and hence a high percentage of sugar. In order to determine the value of depth and direction respectively, the data for each character were tabulated separately and summarized in table VII.

There appears to be no correlation between direction of furrows and percentage or quantity of sugar. It is different, however, in regard to depth of furrows. Shallow furrows are apparently another character of relatively low breeding value. Deep furrows, on the contrary, are correlated with a large quantity of sugar, and roots possessing them show no diminution in percentage of sugar when compared with somewhat smaller roots with shallow furrows.

Considerable difference of opinion prevails regarding the most desirable growing habit of beet foliage, *i. e.*, direction assumed by the leaves. Leaves rising above the ground and having an approximately right-angled exposure to the sun's rays are generally preferred, but the flat or rosette type also has its adherents. In table VIII of the present paper, three types of foliage are compared; erect, semi-erect, and flat.

As shown in the table, the flat or rosette type is correlated with heavy weight and high percentage of sugar, while the erect type indicates low percentage. Although the difference in percentage is very small when due regard is given to probable errors and a proper allowance made for difference in root weight, these results tend to confirm those of Vychinski (5), Karmrodt,[5] and Marek,[6] who claim that flat foliage is correlated with a higher percentage of sugar than are leaves of the erect type. The semi-erect type, however, seems to be fully as desirable as the flat.

The relationship of chlorophyll to photosynthesis suggests a possible correlation between color of foliage and sugar content but as an abundance of nitrates usually stimulates growth and imparts a deep green color to the foliage, and beets grown under these highly nutritive conditions are often low in sugar, the significance of color is not even theoretically established. The experimental results obtained are summarized in table IX.

When due consideration is given to probable errors no constant relationship is exhibited between percentage of sugar and color of foliage.

It has been fairly well proven that quantity of leaves[7] and yield of sugar per acre are positively correlated, but the quantity of leaves per beet is difficult to determine at the time of harvest as beet leaves complete their growth in from four to six weeks, then gradually dry up and drop off as new leaves are developing. Therefore, the relationship was determined between sugar content and leaf dimension. The results are presented in table X.

The data show that size of root and quantity of sugar increase with leaf dimension.

As the character of the leaf surface may influence the amount of photosynthetic work done by the plant, two types, namely, smooth and wrinkled, were compared. Their average performance is expressed by the biometrical constants of table XI.

The chief difference between these types lies in their correlation with percentage of sugar. Beets having smooth leaves were the richer, which is directly opposite to the results reported by Vychinski (5), who claims that saccharine richness increases directly as the quantity of wrinkling.

Three groups of beets were made upon the basis of leaf texture and their relative values recorded in table XII. As used in this paper, texture refers chiefly to thickness and pliability, a thin blade easily folded denoting fine texture.

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[5] Cited by Plahn (6).

[6] Cited by Fruwirth (1).

[7] Maercker, cited by Plahn (6).

Contrary to expectation, fine leaf texture was found to be correlated with large roots. Ordinarily this would signify a greater quantity of sugar but a lower percentage, which is hardly substantiated by the present table although the difference in percentage is slightly in excess of three times the probable error of the difference.

Three types of leaf margin were compared; undulate, sinuate, and curly. The curliness was confined to the outer portion of the leaf, at and near the margin. The relative efficiency of the types for producing sugar is shown in table XIII.

The data show no difference in the value of these types. The plants having a sinuated border produced the least sugar, but this was due to the small size of their roots.

From a knowledge of correlations between the various parts of an individual, we should expect to find large petioles correlated with large roots and hence with a large quantity but low percentage of sugar. The relationship of petiole dimension to sugar content is shown in table XIV.

There is apparently no preference in petiole dimension with respect to percentage of sugar when due allowance is made for differences in root weights (cf. fig. 1). The total sugar, however, increases with the size of the petiole, which is especially marked in connection with breadth.

The groove in the upper surface of the leaf stalk was divided into three grades on the basis of depth and a summary, table XV, was made of their relationships to percentage and quantity of sugar in the root.

As both size of root and quantity of sugar vary with the depth of groove in the petiole without any dimunition in percentage of sugar, this character appears to have an important bearing on yield.

Synthetic Types

By aid of the foregoing data, three different types of sugar beets, designated respectively by the letters *A*, *B* and *C*, have been formed by combining in *A* characters correlated with relatively low sugar production and in *B* and *C* characters correlated with both a large quantity and a relatively high percentage of sugar. Type *A* was based entirely upon the character of the crown and root furrows, as the addition of other characters would have eliminated many roots and made the number otherwise available composing this class too small for satisfactory comparison. Types *B* and *C* contain two extra characters, viz., type of leaf surface and depth of petiole groove, which are probably significant, and a number of other neutral characters which as shown in preceding tables have no bearing on sugar production. While types *B* and *C* are opposite to type *A* only in the characters which constitute *A*, they are nevertheless sufficiently distinct to determine whether morphological characters play any part in the relative performance of beet types.

Description of Types

Type *A*

Crowns: conical. Root furrows: shallow

Type *B*

Root:
  Shape: conical (neutral)
  Crown: flat or rounded
  Furrows: deep
Foliage:
  Color: dark green (neutral)
  Habit of growth: semi-erect or flat (neutral)
Leaf:
  Surface: smooth
  Texture: smooth
  Texture: medium or coarse (neutral)
  Relative area: medium (neutral)
Petiole:
  Groove: deep

Type *C* is identical with *B* except in root form, type *C* having pyriform roots.

The data belonging to these types were separated from those of the general population and tabulated under their respective headings. Hence, no breeding was done. Records of beets embodying the different characteristics were merely picked out from the general population. Both the frequency distribution and the relative behavior of the types are shown in the following tables.

Table XVI

Frequency Distribution of Beets Arranged According to Percentage of Sugar in the Beet

Type	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	No. of Plants	Mean	Standard Deviation
A	1	1	1	2	3	5	9	12	12	6	11	5	6	4	2					80	17.07±.11	1.48±.08
B				3	1	3	8	6	13	14	11	10	5	6	2	3			1	86	17.63±.11	1.44±.07
C					2	4	3	9	11	11	12	13	7	8	4	1	2		1	88	17.93±.10	1.40±.07

Table XVII

Frequency Distribution of Beets Arranged According to Quantity of Sugar per Root in Grams

Type	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	No. of Plants	Mean	Standard Deviation
A .	1	1	1	2	0	5	7	8	7	9	10	7	2	5	5	0	3	1	1	1	1	1	1			1	80	74.68±1.75	23.18±1.24
B .			1	0	0	2	5	5	9	8	5	4	6	5	7	7	1	10	3	1	0	3	0	3	0	1	86	87.26±1.76	24.22±1.25
C..				3	4	2	1	2	5	7	4	9	11	7	7	6	7	3	3	2	3	2					88	85.51±1.57	21.88±1.11

The number of individuals in each group is not large but the distributions are fairly regular. While the types do not differ much in behavior, *B* and *C* exceed *A* by several times the probable error both in percentage and quantity of sugar per root. If wrinkled leaf surface and shallow petiole groove had been included in Type *A* the contrast between it and the other types might have been still greater. It is possible that if certain other characters as number of woodrings, size, shape and number of bundles within the woodring, number of leaf-circles (spiral turns), total number of leaves, and character of veining had been included in the investigation, greater differences would have been exhibited between types.

SUMMARY

A statistical study of 3,784 individual sugar-beet plants grown at Brookings, S. D., was made to determine the correlations which exist between certain morphological characters of the plant and the percentage and quantity of sugar in its root. Data collected at Fairfield, Washington, were also used in studying the relationship between weight of root and percentage of sugar, but no data from different

years nor from beets grown in different fields were grouped for this study. Hence each biometrical constant was determined from a single year's crop produced under fairly uniform field conditions. The results obtained from this material were as follows:

1. The coefficients of correlation found between weight of root and percentage of sugar were —.253, —.258, —.254, —.257, and —.499; between weight of root and quantity of sugar, .920.

2. The correlation between percentage and quantity of sugar in roots of 35 grams range in weight was nearly perfect, viz., .93, .96, and .99 but in roots of miscellaneous sizes no correlation was apparent between percentage of sugar and quantity of sugar per root.

3. No correlation was found between the sugar content of the root and type of leaf margin or color of foliage.

4. Shallow groove of petiole, conical crown, and shallow root furrows showed a very small amount of correlation with a relatively low quantity and relatively low percentage of sugar; flat crown, deep root furrows, deep groove of petiole, smooth leaf surface, flat foliage and coarse leaf texture also showed slight evidence of correlation with a large quantity and relatively high percentage of sugar. These correlations were so small, however, as to cast some doubt upon their permanence and practical significance.

5. Contrasting types of sugar beets were formed by making separate combinations of characters slightly correlated with low performance and characters slightly correlated with high performance. The records of beets embodying these characters were picked out from those of the general population and placed in their respective groups. The behavior of the types as shown by their mean values corresponded to the class of characters composing them but the differences were very small.

In conclusion the writer wishes to acknowledge his indebtedness to Dr. J. Arthur Harris for many helpful suggestions.

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